STAR's capabilities on transverse spin measurements
Status of STAR transverse spin analyses
STAR upgrades
Summary

Transverse Spin Results From STAR

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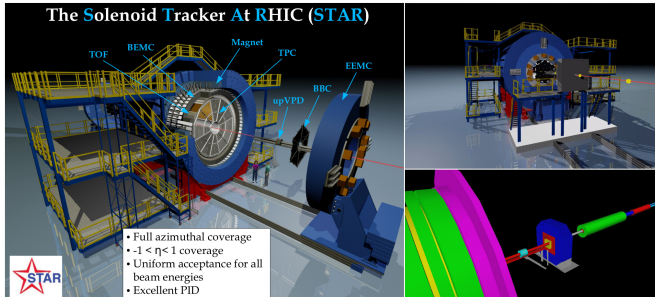2014 RHIC & AGS Annual Users Meeting

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Outline

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STAR's capabilities on transverse spin measurements

The Solenoid Tracker At RHIC (STAR)

- Full azimuthal coverage
- -1 < η< 1 coverage
- Uniform acceptance for all beam energies
- Excellent PID

Detector capabilities

- Central Region ($-1 < \eta < 1$): $\pi^{\pm}$/K/p ID by dE/dX and TOF, $e^{\pm}/\gamma$ by EMCAL, jets

- Mid-Forward ($1 < \eta < 2$): π^0, η, direct γ, EM-jets from Endcap-EMCAL

- Forward ($2.5 < \eta < 4.0$): π^0, η, EM-jets by Forward Meson Spectrometer

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STAR's capabilities on transverse spin measurements

Central Region ($-1 < \eta < 1$)

- inclusive jet A_N, Collins/IFF asymmetries A_{UT}
- $W^{\pm}/Z^0$ boson A_N

Mid-Forward ($1 < \eta < 2$)

- π^0, η, EM-jets A_N

Forward ($2.5 < \eta < 4.0$)

- π^0, η A_N
- topology dependence of A_N through EM-jet/π^0, forward-forward/forward-central correlations

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Mid-rapidity inclusive jet A_N
Collins/IFF Asymmetries
$W^{\pm}/Z^0$ boson A_N
Forward π^0/EM-jet A_N on FMS

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Mid-rapidity inclusive jet A_N

- Corresponding parton-jet p_T lower by 0.6-1.4 GeV/c
- Sensitive to Sivers function

$$\Delta^N f_{a/A\uparrow} \otimes f_{b/B}$$

$$T_F^q(x, x) = -\int d^2\vec{p}_\perp \frac{\vec{p}_\perp^2}{M} f_{1T}^{\perp q}(x, \vec{p}_\perp^2)|_{SIDIS}$$

- Gluon-Gluon scattering dominates due to low x_T
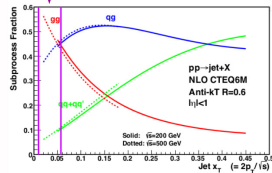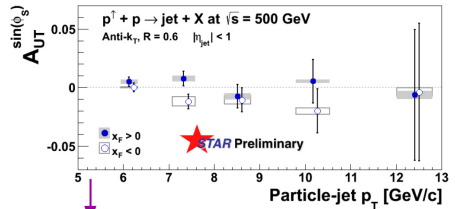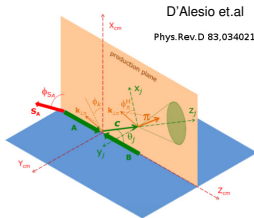
D'Alesio et.al

Phys.Rev.D 83,034021

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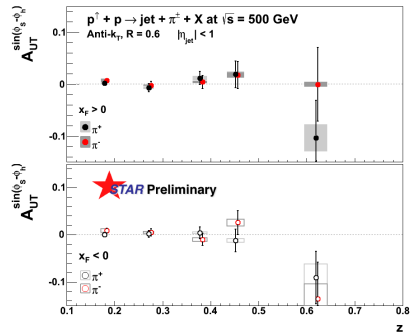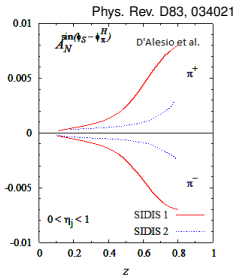Forward π^0/EM-jet A_N on FMS

Collins Asymmetries at 200 GeV

- 2-scale process described within TMD scheme by $h_1^a \otimes f_{b/B} \otimes \Delta D_{\pi/q^\uparrow}$ assuming factorization

- 2012 STAR data provide higher precision and reduced systematic uncertainties. Preliminary results aimed for SPIN2014
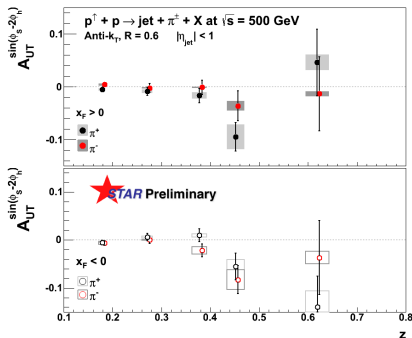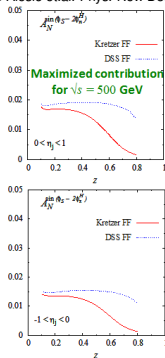

Collins Asymmetry $A \equiv 2\langle\sin(\phi_S - \phi_h)\rangle$ vs. z

AIP Conf. Proc. 1441, 233 (2012)

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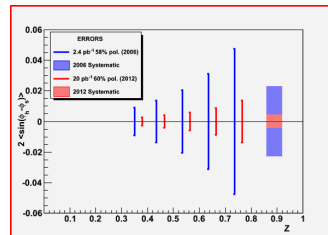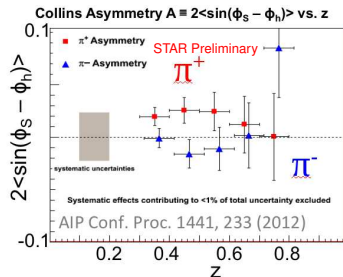
Collins Asymmetries at 500 GeV

- Moments of $\sin(\phi_s - \phi_h)$ sensitive to quark Collins asymmetry

- Increased gluonic subprocess at $\sqrt{s} = 500$ GeV leads to small Collins asymmetries until large z_h

Phys. Rev. D83, 034021

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Collins Asymmetries at 500 GeV

D'Alesio et.al. Phys. Rev. D83, 034021

- Moments of $\sin(\phi_s - 2\phi_h)$ sensitive to linearly polarized gluons
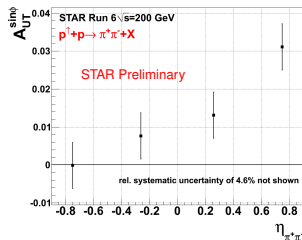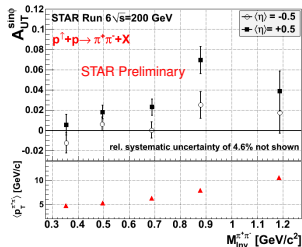- Gluon Collins-like asymmetries completely unconstrained

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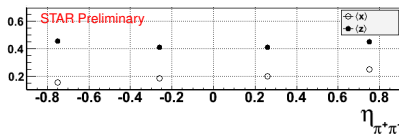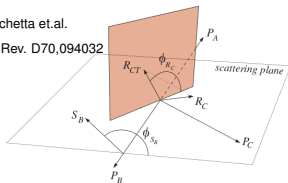Forward π^0/EM-jet A_N on FMS

IFF Asymmetries for Di-hadron correlations
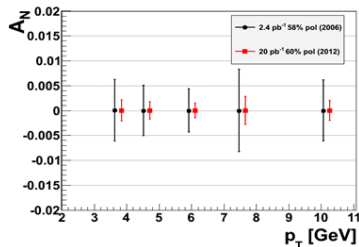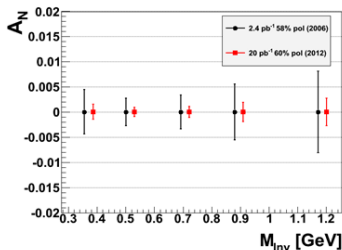
- Asymmetries persist in collinear scheme through
  $$h_1^{a/A^{\uparrow}} \otimes f_{b/B} \otimes H_{1,ot}^{\angle c/C}$$

- First signal of transversity in *pp* collisions

A.Bacchetta et.al.

Phys. Rev. D70,094032

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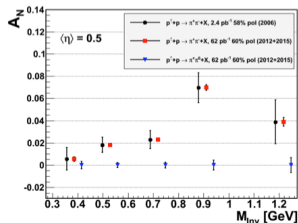Forward π^0/EM-jet A_N on FMS

IFF Asymmetry projections with 2012 STAR Data @ 200 GeV

Statistical uncertainties greatly reduced.

Analyses of 200 GeV and 500 GeV data are ongoing

Preliminary results aimed for SPIN2014

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Sivers function

The sign change of Sivers function
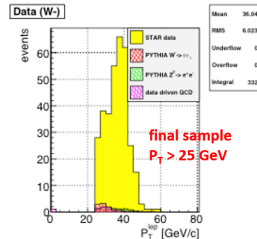
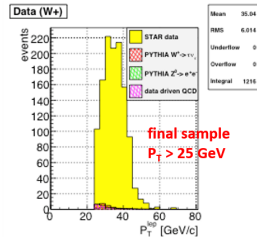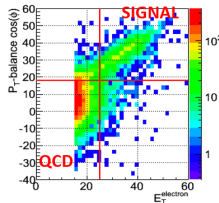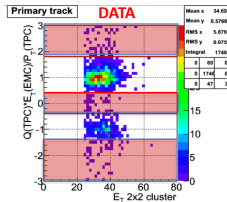Critical test for TMD factorization and evolutions
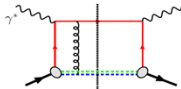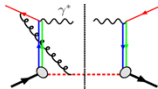
Modified Universality

- $Sivers_{SIDIS} = -Sivers_{DY} = -Sivers_{W^\pm/Z^0}$

- A_N^γ measures the sign change through Twist-3

- $A_{UT}^{Sivers/SIDIS}$, A_N^{DY} and $A_N^{W^\pm/Z^0}$ together test TMD evolutions

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$W^{\pm}$ identification

- $W^{\pm}$ identified via high p_T isolated electrons + p_T imbalance on the away-side
- 2011 500GeV pp collisions, $\mathcal{L} = 25pb^{-1}$

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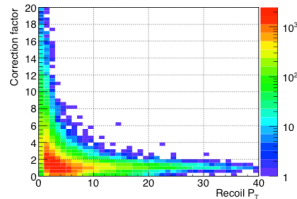Forward π^0/EM-jet A_N on FMS
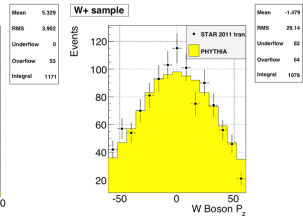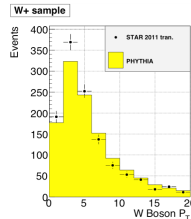
$W^{\pm}$ kinematics reconstruction

- $P_T^W = -P_T^{recoil}$ (MC corrected)
- $P_Z^W = P_Z^e + P_Z^\nu$, neutrino P_Z calculated by
  $M_W^2 = (E_e + E_\nu)^2 - (\vec{p_e} + \vec{p_\nu})^2$
- Neutrino P_T is reconstructed from missing P_T
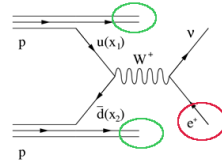
P_T^{recoil} corrected by MC to account for acceptance

Good agreement between data/MC after P_T correction

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$W^\pm/Z^0$ boson A_N From 2011 STAR Data

M.G. Echevarria et.al Phys. Rev. D 89, 074013

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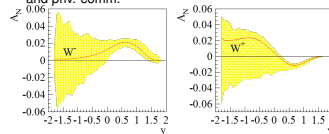
sea quark Sivers function constrained by positivity bound

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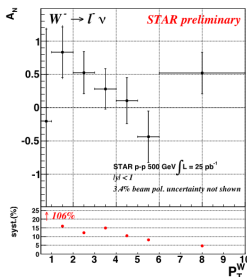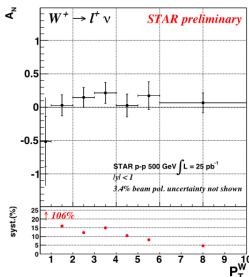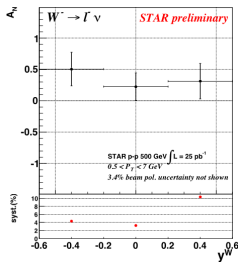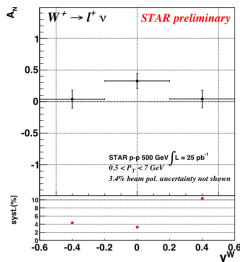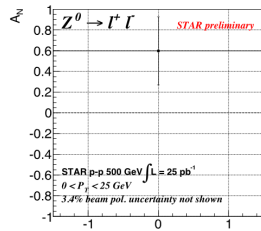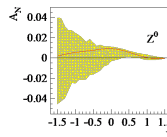
$W^{\pm}/Z^0$ A_N Projections for 2016

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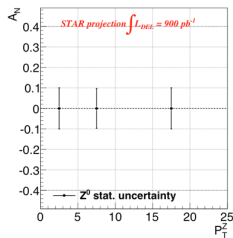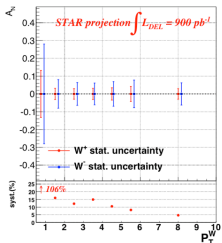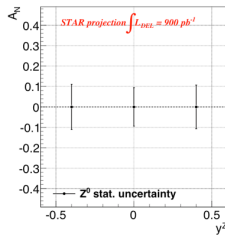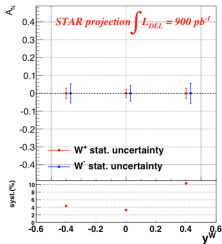
Outline

(1) STAR's capabilities on transverse spin measurements

(2) Status of STAR transverse spin analyses
  - Mid-rapidity inclusive jet A_N
  - Collins/IFF Asymmetries
  - $W^\pm/Z^0$ boson A_N
  - Forward π^0/EM-jet A_N on FMS

(3) STAR upgrades
  - refurbished FMS + Preshower
  - Forward tracking + calorimeter for 2020

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Forward Meson Spectrometer

- Pb Glass calorimeter provides EM coverage in $2.5 < \eta < 4.0$

- small cells: $3.81 x 3.81 cm^2$
  large cells: $5.81 x 5.81 cm^2$

- detect π^0, η and jet-like events

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π^0 A_N
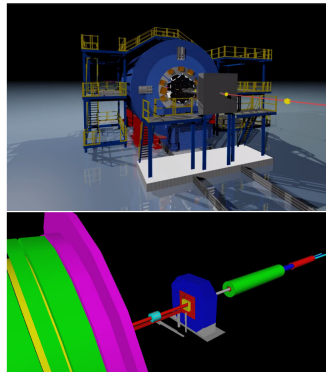
- Isolated π^0 from 2011 data shows flat p_T dependence

- Analysis of inclusive π^0 A_N is ongoing

- A successful twist-3 model (initial-/final-state, or both) would have to explain SSA in *pp* and SIDIS with the same set of parameters, plus evolutions
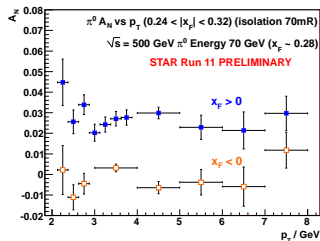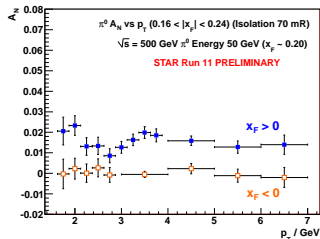
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A_N for forward jet-like events

- Apply Anti-k_T jet finding on FMS photons, R = 0.7

- Isolated π^0 has larger asymmetries than jet-like events

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- Study dependence of A_N on number of photons and away-side jet activities

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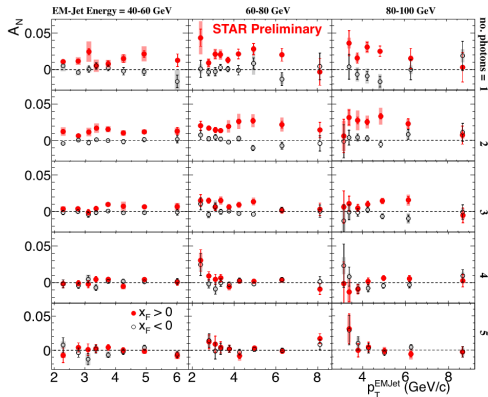**Forward π^0/EM-jet A_N on FMS**
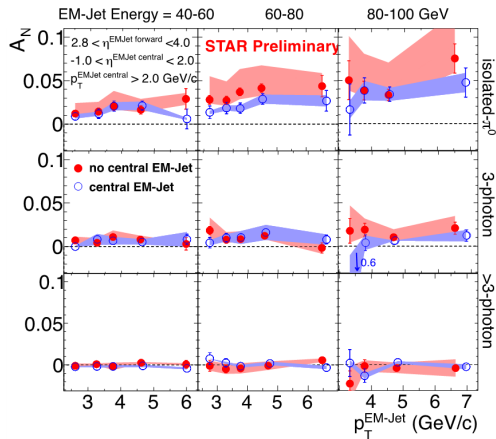
A_N for forward jet-like events

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with and without a central EM-jet
$p_T^{EMjet} > 2.0$ GeV

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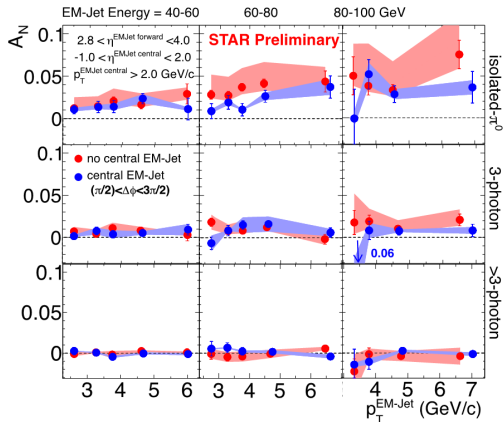
with and without a correlated central EM-jet on the away-side
$p_T^{EMjet} > 2.0$ GeV

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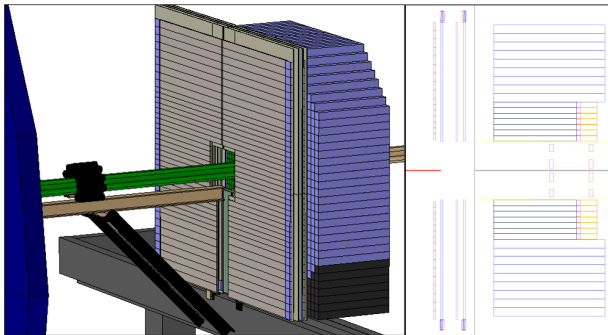Summary

refurbished FMS + Preshower
Forward tracking + calorimeter for 2020

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# Direct γ with FMS + Preshower detector for Run15

- FMS lead glass was exposed to sunlight to recover from radiation damage
- first two layers of preshower provides γ/charged-track separation and (x,y)
- 3rd layer of preshower separates electrons and γ from charged hadrons

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Direct γ A_N for Run15
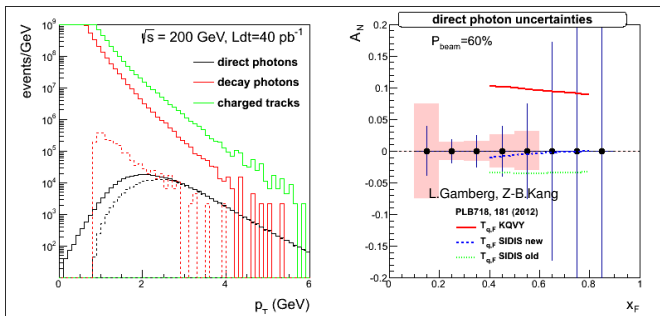
- $p^\uparrow + p$ @ $\sqrt{s}$ = 200 GeV, $\mathcal{L} = 40pb^{-1}$, *pol.* = 60%
- track matching between FMS and layer1 & 2 of preshower
- $E_{cluster} > 15$ GeV, $p_T > 2.0$ GeV

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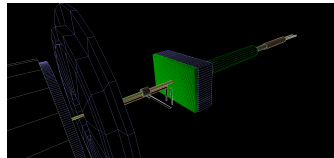Status of STAR transverse spin analyses
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Forward Tracking & Calorimeter System for 2020

- ECAL: W powder + scintillating filters
  σ_E / E = 0.11/$\sqrt{E}$ + 0.007
- HCAL: Lead plates + scintillating tiles
  σ_E / E = 0.58/$\sqrt{E}$ + 0.007
- Prototypes tested extensively at Fermilab

- Silicon micro-strip technology based on experience from STAR IST
- GEM technology from FGT design
- Still in early stage of development

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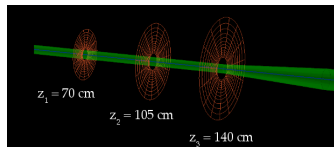
Summary

- STAR continues to deliver high quality transverse spin measurements for

  - Mid-rapidity jet A_N to probe gluon Sivers function

  - Mid-rapidity correlations to access transversity

  - $W^{\pm}/Z_0$ asymmetries to test TMD factorization & evolutions

  - A_N for forward hadron/jet-like events to shed light on the origins of the large transverse spin effects

- STAR upgrades in the (near-) future will enable new exciting measurements

  - Forward direct photon

  - Forward jet, di-hadrons. . .

Stay tuned!

Backup –2006 jet A_N, A_Σ and A_{TT}

$d\sigma_{pol}/d\sigma_{unpol}$
$= 1 + P_1 P_2 \cdot A_\Sigma(\eta, p_T) + \cos(\phi) \cdot [P_1 \cdot A_N(\eta, p_T) - P_2 \cdot A_N(-\eta, p_T)] + P_1 P_2 \cdot \cos(2\phi) \cdot A_{TT}(\eta, p_T)$

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